

# CONSOLIDATED COMMUNICATIONS FOR LOW-COST PLANETARY MISSIONS

Joseph 1. Statman  
Ernest W. Stone  
Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California

## Abstract

*As pari of reducing the cost of operating Deep Space planetary missions, the Jet Propulsion Laboratory (JPL) has developed and deployed a highly-accurate digital receiver capable of recovering telemetry at rates as high as 26 Msymbols/s. This receiver a/so provides interim products needed for navigation (ranging and Doppler) and open-loop recording for radio-science. JPL is currently assessing the consolidation of all of these functions (receiving, telemetry, ranging, doppler, and open-loop recording) into a single rack that could be remotely controlled to support all the downlink functions of the mission support. When deployed, it will provide an operationally efficient downlink processor that can be run from the mission's operations center, as well as from a Principal Investigator's office. An additional benefit will be the improved performance and reliability enabled via advanced technology (e.g. turbo-code decoder with a 2. 5-dB advanfage over the standard CCSDS error-correcting code, almost doubling the available downlink rate). Without this consolidation, the telemetry, navigation, and radio-science mission support would require separate, sometimes overlapping, suites of operational support increasing the cost of mission support This paper discusses the motivation, de fails, and benefits of this consolidation,*

## 1. INTRODUCTION

Is there such a thing as a free lunch? When it comes to communications with planetary missions, the answer could be "No, but how about buy-one-get-two-more-for-free?" Consider that a typical planetary mission utilizes the same communications link between the spacecraft and Earth to support three distinct services, often at the same time:

- (a) A Communications service, i.e., uplinking commands to the spacecraft and downlinking science and status telemetry.
- (b) A Navigation service, i.e., inferring the spacecraft trajectory from the uplink/downlink performance, primarily via the measurement of the ranging code(s) and the Doppler frequency and rate.

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- (c) A Radio-Science (R/S) service, i.e., observing the minute perturbations in the amplitude, phase, and frequency of the received downlink and relating them to physical phenomena such as solar scintillation and gravitational waves.

Could these three services be fulfilled using Earth-orbiter support equipment? Unlike planetary missions, Earth-orbiters usually use the link only for the Communications service - navigation is accomplished via GPS and there is no significant R/S to be derived from the communications link. The special stability and sensitivity of these two latter services need to be 'designed in,' otherwise, applying existing Earth-orbiter equipment to planetary missions could result in second-rate Navigation and R/S services, or in the need to invest sorely needed funds in expensive enhancements.

The Jet Propulsion Laboratory (JPL) has been providing the three services for planetary missions via its Deep Space Network (DSN). Recently, JPL has deployed a new generation of fully-digital receivers that support the Communications, Navigation, and R/S services. Currently JPL is assessing the consolidation of the signal processing functions associated with that support to reduce the cost of routine operation and enable closer involvement by the mission's Principal Investigators (PIs) in directing the support. In this paper we review the specific characteristics of the Communications, Navigation, and R/S services (Section 2) and how the equipment developed by JPL addresses the three services in one suite (Section 3).

## 2. THE COMMUNICATIONS, NAVIGATION, RADIO-SCIENCE SERVICES

The typical equipment configuration for spacecraft support is shown in Figure 1. On the uplink side, the command and navigation signals are modulated and transmitted to the spacecraft using an RF signal. On the downlink side, the received RF signal is tracked by the receiver, then its telemetry, navigation, and R/S components are recovered.

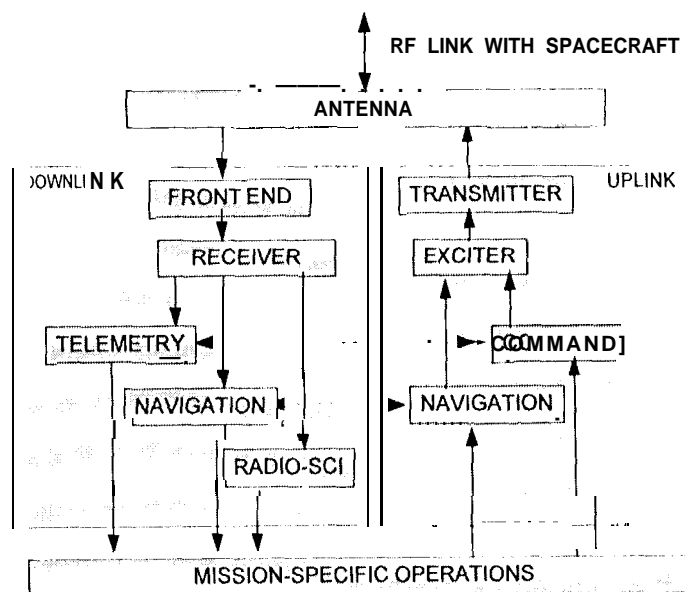


Figure 1- Model for Spacecraft Ground Support

The Communications service recovers frames of decoded telemetry in an agreed-upon format and provides them to the mission. Usually the service will conform to the CCSDS<sup>1</sup> standards [1]. Figure 1 indicates a feedback path between the command and telemetry functions, providing acknowledgment that commands were received by the spacecraft. While at present this acknowledgment and retransmission service is usually manual, there are benefits in embedding it in the protocol, in a manner similar to the TCP/IP implementation, making it transparent to the user.

The Navigation service provides measurements of the range to the spacecraft and its Doppler signature. Both measurements tend to be two-way, i.e. a ranging code and a Doppler reference are transmitted to the spacecraft, where a transponder simply echoes them to Earth, with a simple frequency translation. The ground measurements are the range, phase and frequency differences between the transmitted reference and the received signal. The estimated spacecraft trajectory is then derived from these measurements.

The R/S service records the spectrum of the received signal, primarily near the carrier frequency. The filtered spectrum is usually provided to the PI for further processing.

Since the product of the R/S service - digitized frequency band - simply captures the physical phenomena with minimal pre-processing, it enables other special science and mission activities. To name a few, the products of the R/S service can be used to capture the return of planetary radar, where radar beams are bounced off planetary objects such as planets and asteroids. It can also be used to capture, for later processing, the signal from missions where signal lock is difficult, such as either probe/penetrator missions or missions that deploy a large number of objects near a planetary object. For such missions, the R/S service is an ideal backup to the prime communications link.

Figure 2 shows the architecture used in the DSN to perform these services. The Block V Receiver (BVR) [2] development was initiated in 1989 and operational BVRS were deployed at all the DSN complexes in mid-1995. It is a fully digital receiver that is based on three JPL-developed GaAs ASICs, each with more than 160,000 used gates. Figure 3a shows the JETSYM ASIC while Figure 3b shows the BVR DSP board, where all the digital processing occurs. The BVR performs all the functions that are common to the three services, namely the RF-to-IF conversion, high-rate (160-MHZ) sampling, and the carrier recovery. Because the telemetry can be in a suppressed carrier mode, the soft symbol recovery is included in the BVR as well (to recover a suppressed carrier signal, the carrier and symbols are recovered jointly rather than sequentially).

Note the "low-cost" of the R/S service in this implementation. Most of the BVR components are required to fulfill the Communications service. The only added

<sup>1</sup>CCSDS = Consultive Committee for Space Data Systems

components traceable to the R/S service are two boards: a single board (fitting in the existing BVR backplane) that performs the filtering to the demanding standards of R/S, and the follow-on CPU board to format and send the resulting packets to the PI.

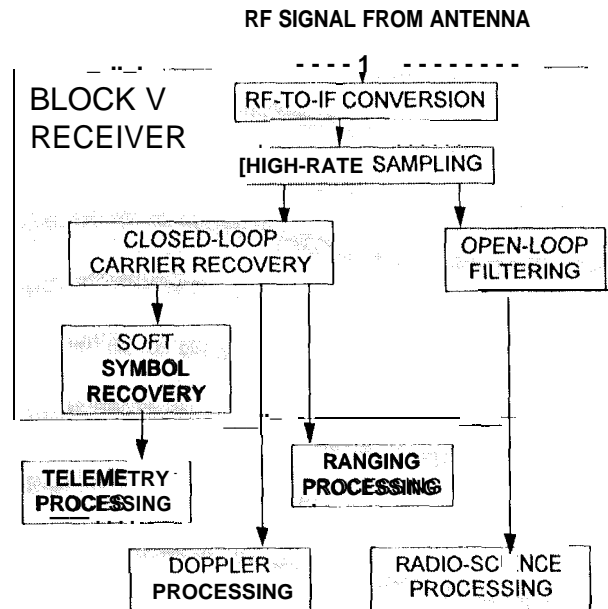


Figure 2- Block V Receiver - Functional Components

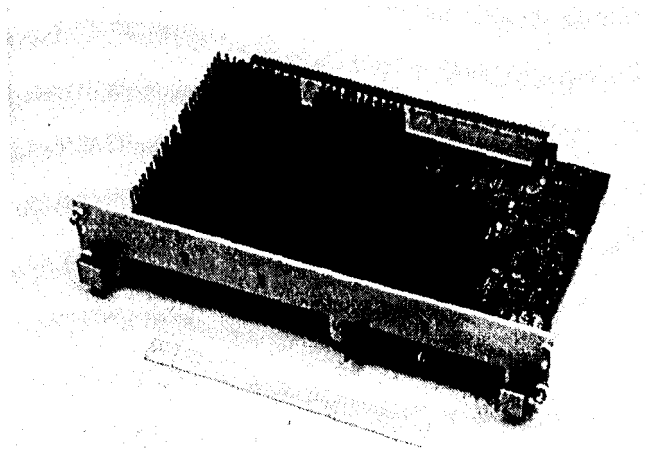


Figure 3a - Block V Receiver Key Components - JETSYM ASIC

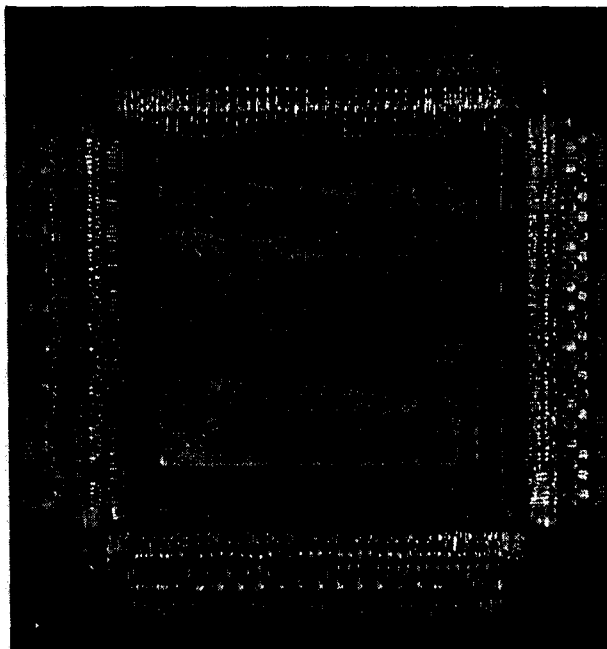


Figure 3b - Block V Receiver Key Components - DSP Board

### 3. **EQUIPMENT CONSOLIDATION**

The proposed consolidation for a single antenna is shown in Figure 4. The guiding principle is to locate only the minimal necessary equipment at the antenna site, and place most of the electronics and (corresponding control) at a central site, simplifying operations and maintenance.

The cornerstones of the consolidation are the boxes marked "Uplink Processor" (ULP) and "Downlink Processor" (DLP). Each ULP and DLP is physically implemented in a single 19" rack. The pair of ULP and DLP racks could be placed at the DSN Signal Processing Center, or at any non-DSN antenna. It requires minimum interfaces: to/from IF, to/from digital network, and timing/frequency references, resulting in a convenient, self-contained unit that supports all the mission communication link needs.

#### 3.1 Downlink Electronics - Highlights

The downlink processor (DLP) is based on the BVR, with extensions to complete the Communications, Navigation, and R/S services. The key functions executed in the downlink processor are:

- (a) Carrier recovery for both suppressed carrier and non-suppressed carrier signals. The implementation employs high-resolution processing to enable high-precision measurements such as gravity wave exploration.

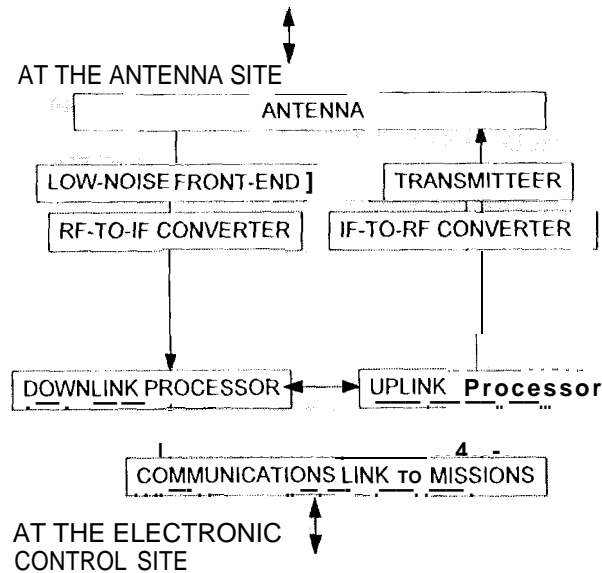


Figure 4- Physical Partitioning

- (b) Telemetry recovery. The DLP recovers BPSK and QPSK telemetry both in direct modulation and residual carrier modes, at rates from 4 symbols/sec to 26 Msymbols/s.

The DLP decoder uses a frame-based architecture. As shown in Figure 5, frames are detected in the symbol domain. The frames of symbols, as well as the symbols that cannot be framed, are time-tagged and buffered as annotated data units similar to the present SFDU units. These units are then "sent" to the appropriate decoder for processing.

This architecture provides data capture very early in the process and provides reliable communications and concurrent processing for this data in the subsequent stages. It also allows for the reverse recovery of the symbol stream when frame decoding and verification processes are used. It is very suitable for incremental implementation of high-speed decoders, e.g. build a 1-Mbits/s Viterbi decoder for (15,1/6) convolutional code and then use several of these cards in parallel to achieve any desired higher rate. The architecture is also suitable for expansion to any future frame-based error-correcting codes. For example the recently discovered Turbo codes [3] will be decoded by a single-card decoder in the VME chassis.

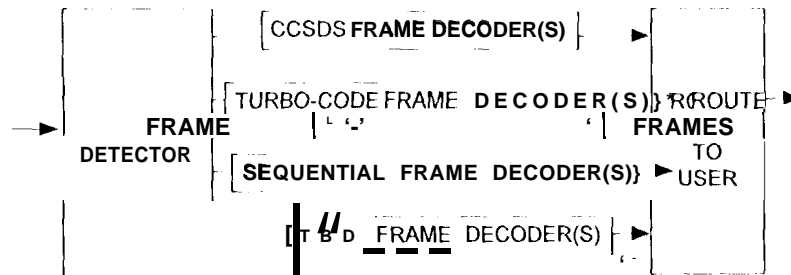


Figure 5- Decoder architecture

- (c) **Ranging recovery.** The DLP provides for the recovery of the sequential as well as the pseudo-random ranging codes. The DLP output is a time-tagged Earth-arrival time of a marker in the ranging code that, combined with the time-tagged earth transmit time, can be converted to a range.
- (d) **R/S recovery.** The DLP stability and filtering enable high-resolution, high-stability recording of a bandwidth (up to 100 KHz, I/Q components) of interest to R/S. The recorded data is formatted and forwarded to the P1.

### 3.2 Monitor and Control

The DLP and the ULP could be operated in two modes: in the DSN-mode, the equipment is operated from a standard DSN console as part of a DSN link while in the Pi-mode the equipment is operated by an external PI. Though the interfaces and the displays may be significantly different, the equipment operation remains the same. The PI mode would be available primarily to experienced and knowledgeable PIs who are interested in taking direct control of the equipment while assuming at the same time responsibility for the results.

## 4. IMPLEMENTATION CONSIDERATIONS

Let's expand the downlink portion of Figure 4 to the DSN case where multiple collocated antennas are being serviced. Two architectures are possible. In the first, shown in Figure 6, multiple DLPs are connected to the antennas via an IF switch. In this architecture, the DSN'S stringent availability requirement is met by augmenting the operational DLPs by additional units. The number of DLPs and the operational concept (hot or cold backups, mean time to repair, etc.) are determined by the particular availability requirement. The alternate approach is to break the DLP into its functional components, provide component pools (telemetry receivers, demodulators, decoders, ranging computers, etc.) and let the operators build "virtual DLP" links by strapping together components in real-time. The latter approach could achieve the same availability with less hardware but at the cost of increased operational complexity and the need to establish and maintain the strapping switches. On balance, the architecture shown in Figure 6 was selected.

The elevation drawing for the DLP is shown in Figure 7. The BVR portions are existing designs that are easily duplicated. The key new part is the added VME-bus chassis that contains boards to perform the follow-on functions, namely decoding, ranging, Doppler formatting, and R/S formatting.

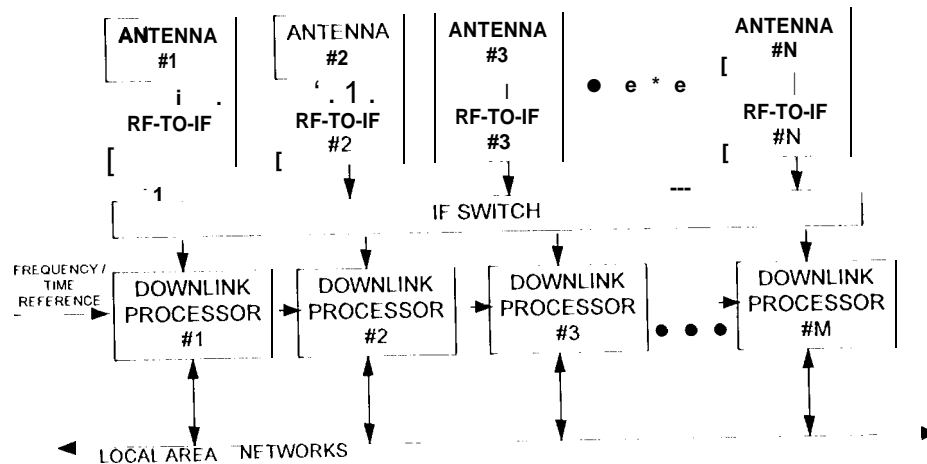


Figure 6- Downlink Architecture

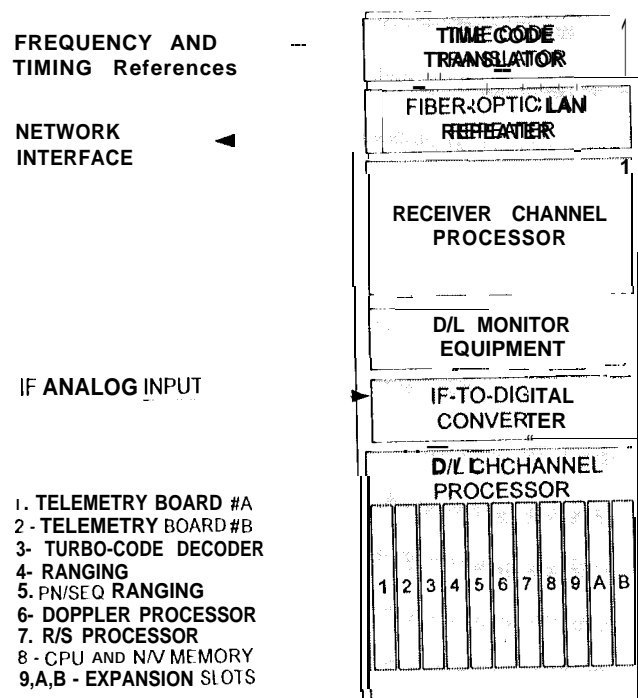


Figure 7- DLP Elevation Drawing (not to scale)

## 5. CONCLUSIONS

We have described an architecture and a set of equipment that is uniquely suitable to support the low cost planetary missions. It will provide the required Communications service as well as enable high-quality Navigation and R/S services. Key components of this equipment have been developed and successfully deployed at

the DSN sites and the implementation of the remaining components is under discussions.

## References

- [1] "Telecommand Part 1 - Channel Service", Recommendation for Space Data Systems Standards, CCSDS Blue Book 202. O-B-1, Issue 1, Washington DC, January 1987 or later Issue.  
  
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- [2] BVR Paper
- [3] Divsalar, D. and Pollara, F., "On the Design of Turbo Codes", TDA Progress Report 42-123, July-September 1995, Jet Propulsion Laboratory, Pasadena, California.